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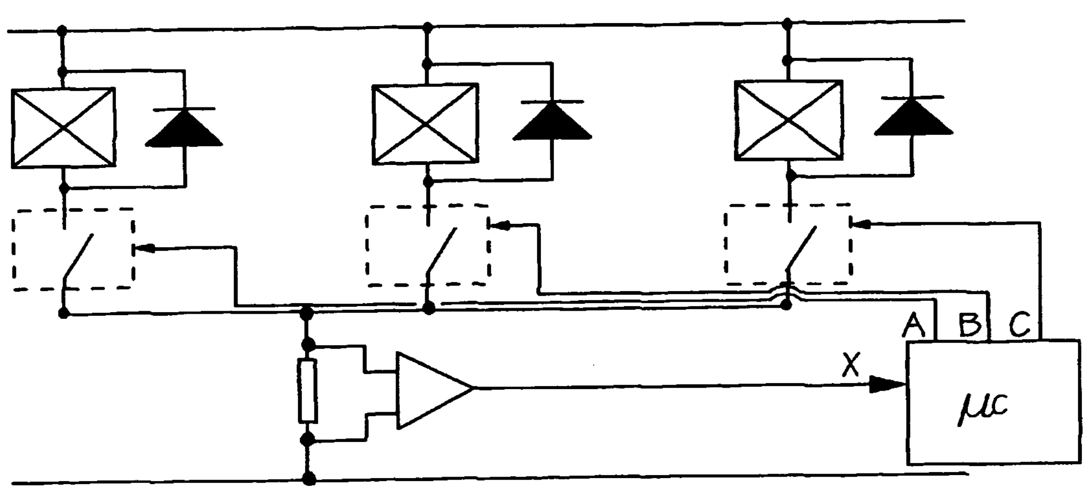
(54) Title: MULTIPLE CHANNEL SOLENOID CURRENT MONITOR



(57) Abstract: An arrangement for monioring multiple channel solenoid currents wherein a plurality of separately controllable solenoid coils (10a, 10b, 10c) are coupled commonly by a single current measurement element (24) to one side of a current supply (16, 18).

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DESCRIPTION

MULTIPLE CHANNEL SOLENOID CURRENT MONITOR

The present invention is concerned with the monitoring of multiple channel solenoid currents particularly, but not exclusively, in automotive electrical and electronic control systems.

There are many situations in electrical and electronic control systems where there is a requirement for the current flowing in a solenoid coil to be monitored and measured. Conventionally, each channel containing an individual solenoid coil has its own current sensing element associated with it. Usually, the sensing element comprises a resistive element, eg. a simple resistor disposed in series with the solenoid coil, whereby the voltage drop across the resistor is proportional to the current flowing through it, and hence proportional to the current flowing through the solenoid coil. The voltage across the resistor is conditioned and read by an analogue to digital converter (ADC).

The known arrangement thus has the associated cost disadvantage that individual sensing elements and conditioning are required for each channel of current to be measured, ie. for each solenoid coil to be monitored.

It would be advantageous to provide, particularly for automotive applications, an arrangement whereby it is no longer necessary for there to be individual sensing elements for each solenoid channel.

In accordance with the present invention, a plurality of separately controllable solenoid coils are coupled commonly by a single current measurement element to one

side of a current supply.

The measurement element can, for example, be coupled to an analogue to digital converter via a signal conditioning amplifier for measurement purposes.

Preferably, the solenoid coils are coupled commonly by said single current measurement element to the low side of the current supply.

In a preferred embodiment, in order to enable the current through any one particular solenoid coil to be measured, means are included for, firstly, enabling a current measurement reading to be made only while a respective drive element for that particular solenoid coil is switched on, and, secondly, switching on the drive element for only that particular coil when the current measurement reading is made, with all other drive elements being switched off.

The first and second means would normally be realized by logic circuit arrangements which are implemented by hardware or software. Software implementation is preferred since the microcomputer which is present in the system for control of the braking system is available for this purpose, so that the additional hardware costs do not arise.

Usually the measurement of the current through the solenoid coils is required for "closed-loop" operation whereby, preferably, the duty cycle of a PWM-signal is varied to control the current through the solenoid coil. Since the present circuit arrangement has a common current measurement element, "closed-loop" operation is not possible. Therefore a so-called "calibration cycle" can be arranged to be passed through for each solenoid coil when the two before-mentioned first and

second conditions can be met. During the calibration cycle, the optimum setting for the PWM duty cycle can be learned. Because the calibration cycles are repeated periodically, a reliable operation can be ensured over the whole running period, even though only "normal" control is possible. This means e.g. that in applications where valves are driven, a correct switching behaviour ("OPEN", "CLOSED" respectively) can be guaranteed.

The invention is described further hereinafter, by way of example only, with reference to the accompanying drawings, in which:-

Fig. 1 is a circuit diagram illustrating a typical example of a known arrangement for monitoring multiple solenoid coils;

Fig. 2 is a circuit diagram illustrating one embodiment of an arrangement in accordance with the present invention for monitoring multiple solenoid coils;

Fig. 3 is an example of an electro hydraulic braking system (EHB) having a plurality of solenoid operated valves to which the present invention can be applied;

Fig. 4 is a circuit diagram illustrating in principle a technique for achieving the control of the timing of the solenoid energisations to achieve operation in accordance with the present invention;

Fig. 5 is a flow diagram illustrating operation of the circuitry of Fig. 4;

Fig. 6 is a timing diagram corresponding to Figures 4 and 5; and

Fig. 7 is a modified flow diagram showing one preferred operation.

Referring first to Fig. 1, there is shown a circuit arrangement having three solenoids whose solenoid coils 10a, 10b, 10c are to be monitored. The solenoid coils

10a, 10b, 10c are disposed between a supply line 16 and ground 18 and are controlled by respective series low side switches 12a, 12b, 12c, for example drive FETs. In parallel with each coil 10a, 10b, 10c is a respective recirculation diode 14a, 14b, 14c. In order to measure the current passing through the solenoids 10a, 10b, 10c, there is disposed between each drive FET 12a, 12b, 12c and ground 18 a respective resistor 20a, 20b, 20c, the voltage drop across each resistor 20a, 20b, 20c being measured by a respective amplifier 22a, 22b, 22c. The outputs of the amplifiers 22a, 22b, 22c lead to respective ADC inputs (not shown) for measurement purposes.

In the arrangement of Fig. 2 in accordance with the present invention, identical components are given the same reference numerals. In this arrangement, the terminals of three FETs 12a, 12b, 12c remote from the coils 10 are connected together and coupled to ground 18 via a single common resistor 24, the voltage across which is monitored by means of a single amplifier 26. The output of the amplifier is again passed to the input of an analogue to digital converter (ADC) for measurement purposes.

It is emphasised that although the illustrated circuit shows three solenoid coils 10a, 10b, 10c, this is purely by way of example and in practice there could be any number of such coils, commonly coupled to ground 18 by the single sensing resistor 24.

Although the circuit illustrated uses FETs as low side drivers, in principle other drive elements, such as relays, transistors and the like, could be used.

The sensing element formed by resistor 24 in the circuit of Fig. 2 detects the

sum of all of the currents flowing through the solenoid coils 10a, 10b, 10c. In order to read the current through any particular single one of the coils 10, two conditions must be met. Firstly, the ADC reading must only be made while the respective drive element 12 for that particular solenoid channel is switched on. Secondly, only the FET 12 for the particular coil 10 being measured should be switched on when the ADC reading is made. All other drive FETs 12 must be switched off. Although not shown in Fig. 2, suitable control circuitry is provided to achieve these two conditions, for example as described hereinafter in connection with figures 4 to 7.

The achievement of the above identified two conditions means essentially that, in order to ensure that a robust measurement can be made, only one active device can be held energised. This is normally achieved through software control of the timing of the solenoid energisations. In principle, it is possible to provide a control circuit as illustrated in the attached modified version of the present figure 2 identified as figure 4. Here, the output X of the device 26 is read on an input port of a microprocessor μ. The signal x is present when one or more of the solenoids are conducting and with suitable control, as idealised in the flow chart of Fig. 5, the output x can be associated with specific solenoid. The actual timing of the associated pulses can be seen from the corresponding timing diagram of Fig. 6.

In practice, due to variations in the supply voltage, the period (mark/space ratio) that is required to provide a suitable energisation current for a solenoid varies such that it is likely that the actual pulse periods for all solenoids overlap. In this case, a control method is required that intentionally holds off the energisation of all

but the monitored solenoid. This can be achieved by interrupting the normal pattern i.e. normal cycle, of solenoid energisations with a measurement cycle at a prescribed frequency, for example 1 in every 10 normal cycle energisations, and by holding off the energisation of all but the monitored solenoid, measurement of each solenoid being achieved by incrementing through the monitored solenoids on each and every other interruption or measurement cycle. In this control regime there would need to be an intentional disabling of the potentially active devices in order to allow current measurement of the chosen device to take place. By way of example only, the flow chart of Fig.7 could be included as part of the microprocessor control of the solenoid energisations that could achieve the desired objective. This control method comprises a normal cycle part which allows uninterrupted operation of the solenoids under control, and a measurement cycle part that is evoked every n'th cycle that disables all solenoids then enables the chosen solenoid for subsequent measurement. After measurement, all solenoids are enabled and the chosen solenoid is incremented to the next in the measurement order. Finally the interrupt counter is reset so as to allow the normal cycle to continue.

In arrangements such as those described above, by having only a single sensing resistor and conditioning amplifier, a substantial cost saving can be made.

Fig. 3 shows an example of a typical practical situation where the use of the present invention can be of cost saving advantage. Fig. 3 illustrates an electro hydraulic braking system where braking demand signals are generated electronically at a travel sensor 28 in response to operation of a foot pedal 30, the signals being

processed in an electronic control unit (ECU) 32 for controlling the operation of brake actuators 34a, 34b at the front and back wheels respectively of a vehicle via pairs of valves 36a, 36b 36c, 36d. The latter valves are operated in opposition to provide proportional control of actuating fluid to the brake actuators 34 from a pressurised fluid supply accumulator 38, maintained from a reservoir 40 via a motor-driven pump 42. For use, for example, in emergency conditions when the electronic control of the brake actuator is not operational for some reason, the system includes a master cylinder 44 coupled mechanically to the foot pedal 30 and by which fluid can be supplied directly to the actuators 34 in a "push-through" condition. In the push-through condition, a fluid connection between the front brake actuators 34a and the cylinder 44 is established by means of digitally operating, solenoid operated valves 46a, 46b. Also included in the system are further digitally operating solenoid valves 48, 50 and 52 which respectively connect the two pairs of valves 36a, 36b, the pump 42 and accumulator 38 and the two pairs of valves 36c, 36d.

The present system of monitoring solenoid coil currents can be applied to monitor the currents in the digitally operated valves 46a, 46b, 48, 50 and 52 by means of a common sensing element 24 and conditioning amplifier 26. It can also be applied to the control valve pairs 36a, 36b, 36c and 36d in the event that they are not provided for a proportional control mode.

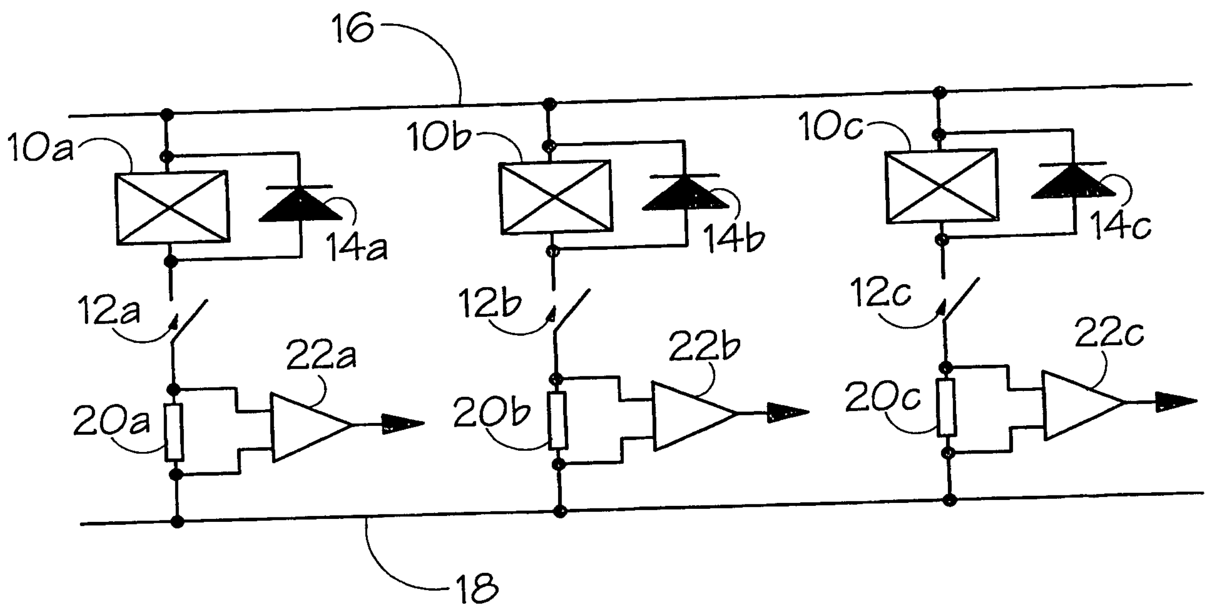
CLAIMS

1. An arrangement for monitoring multiple channel solenoid currents wherein a plurality of separately controllable solenoid coils are coupled commonly by a single current measurement element to one side of a current supply.

2. A monitoring arrangement as claimed in claim 1 wherein the measurement element is coupled to an analogue to digital converter via a signal conditioning amplifier for measurement purposes.

3. A monitoring arrangement as claimed in claim 1 or 2, wherein said plurality of separately controllable solenoid coils are coupled commonly by said single current measurement element to the low side of the current supply.

4. A monitoring arrangement as claimed in claim 1, 2 or 3, wherein in order to enable the current through any one particular solenoid coil to be measured, means are included for, firstly, enabling a current measurement reading to be made only while a respective drive element for that particular solenoid coil is switched on, and, secondly, switching on the drive element for only that particular coil when the current measurement reading is made, with all other drive elements being switched off.


16
10a
10b
10c
14a
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14c
12a
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12c
22a
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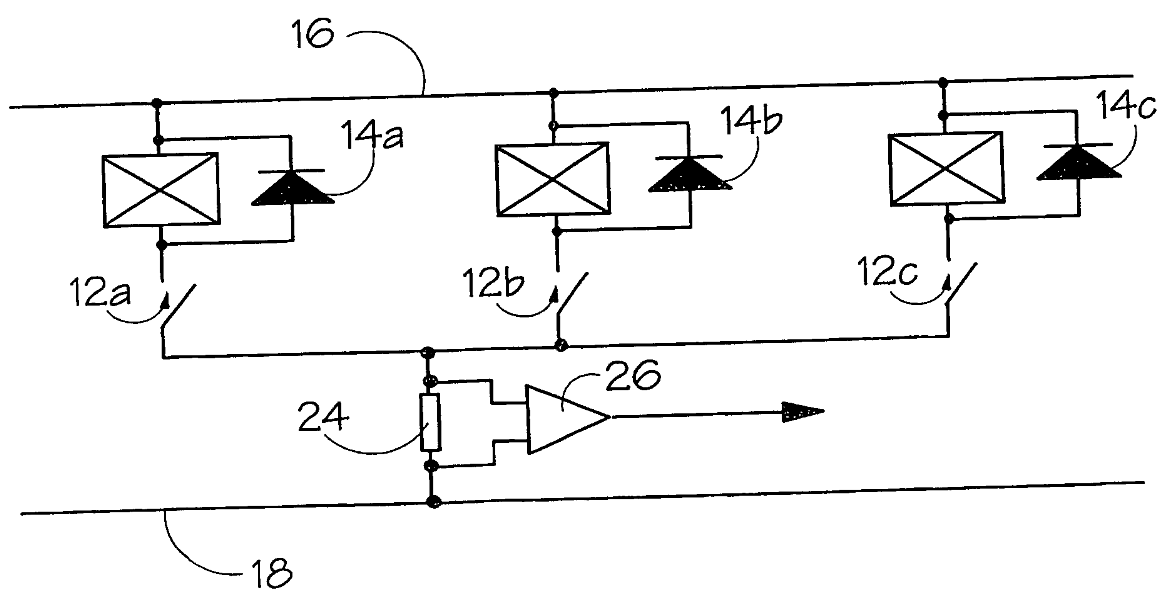
22c
20a
20b
20c
18

FIG.1.


16
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24
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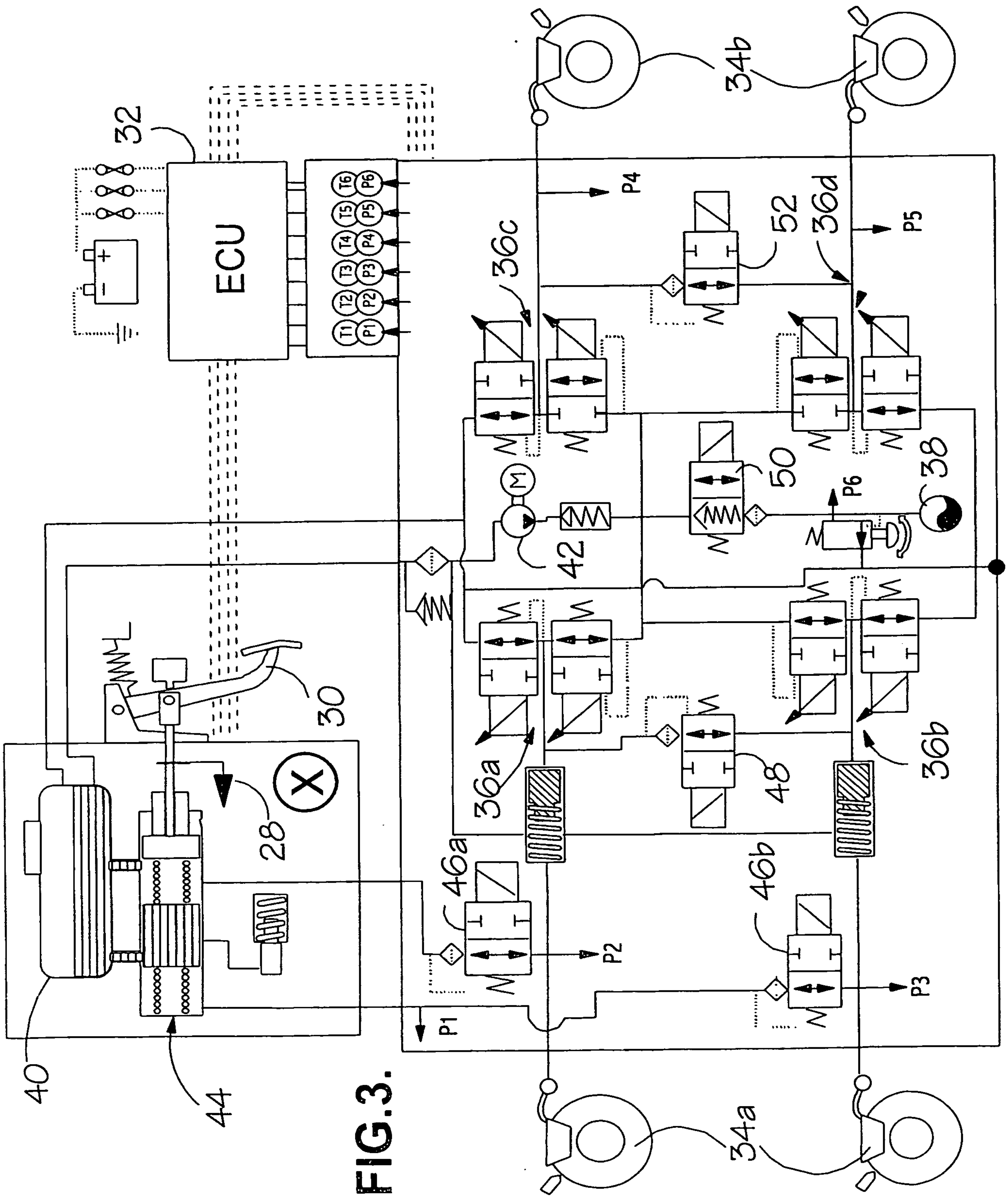
FIG.2.


ECU
32
T1 T2 T3 T4 T5 T6
P1 P2 P3 P4 P5 P6
30
28
40
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46a
46b
36a
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36d
34a
34b
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48
50
52

FIG.3.

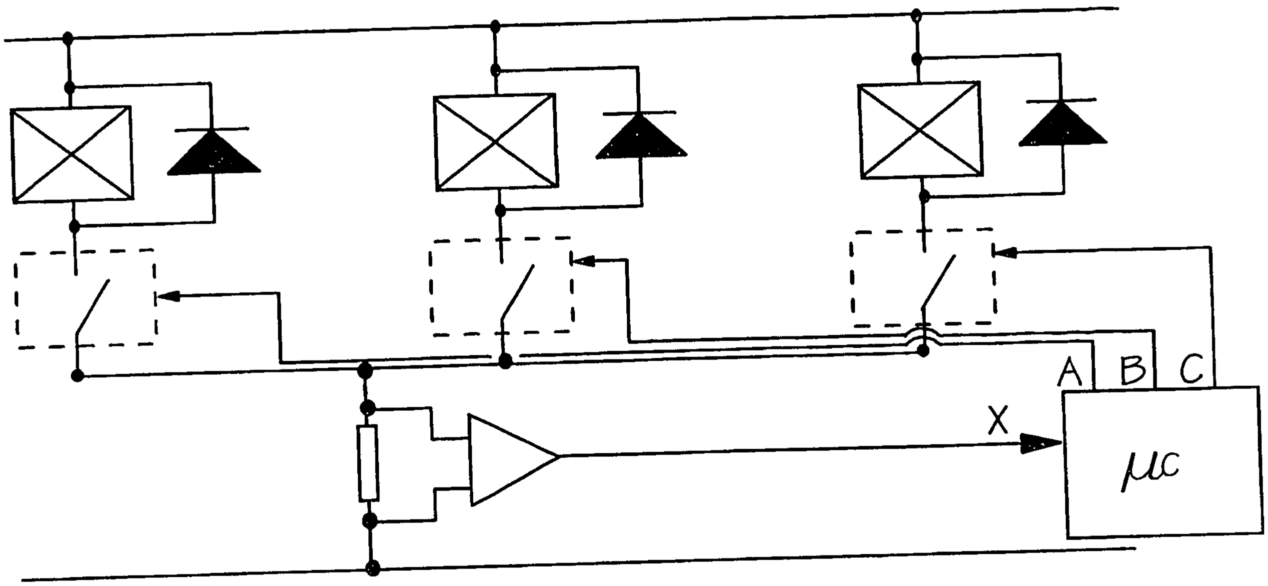

FIG.4.

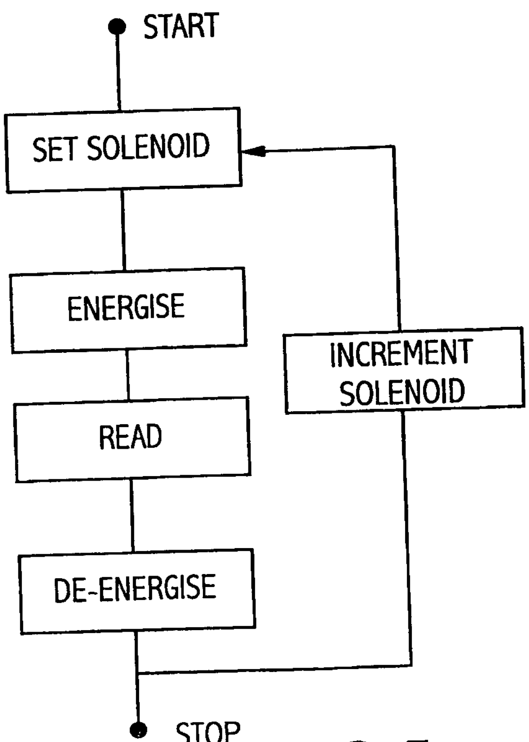

FIG.5.

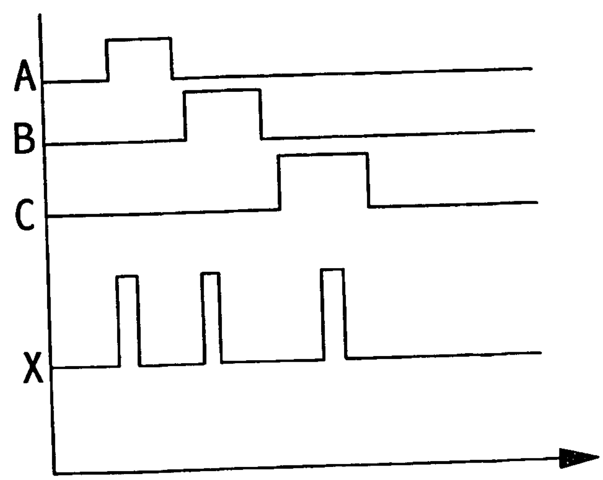

FIG.6.

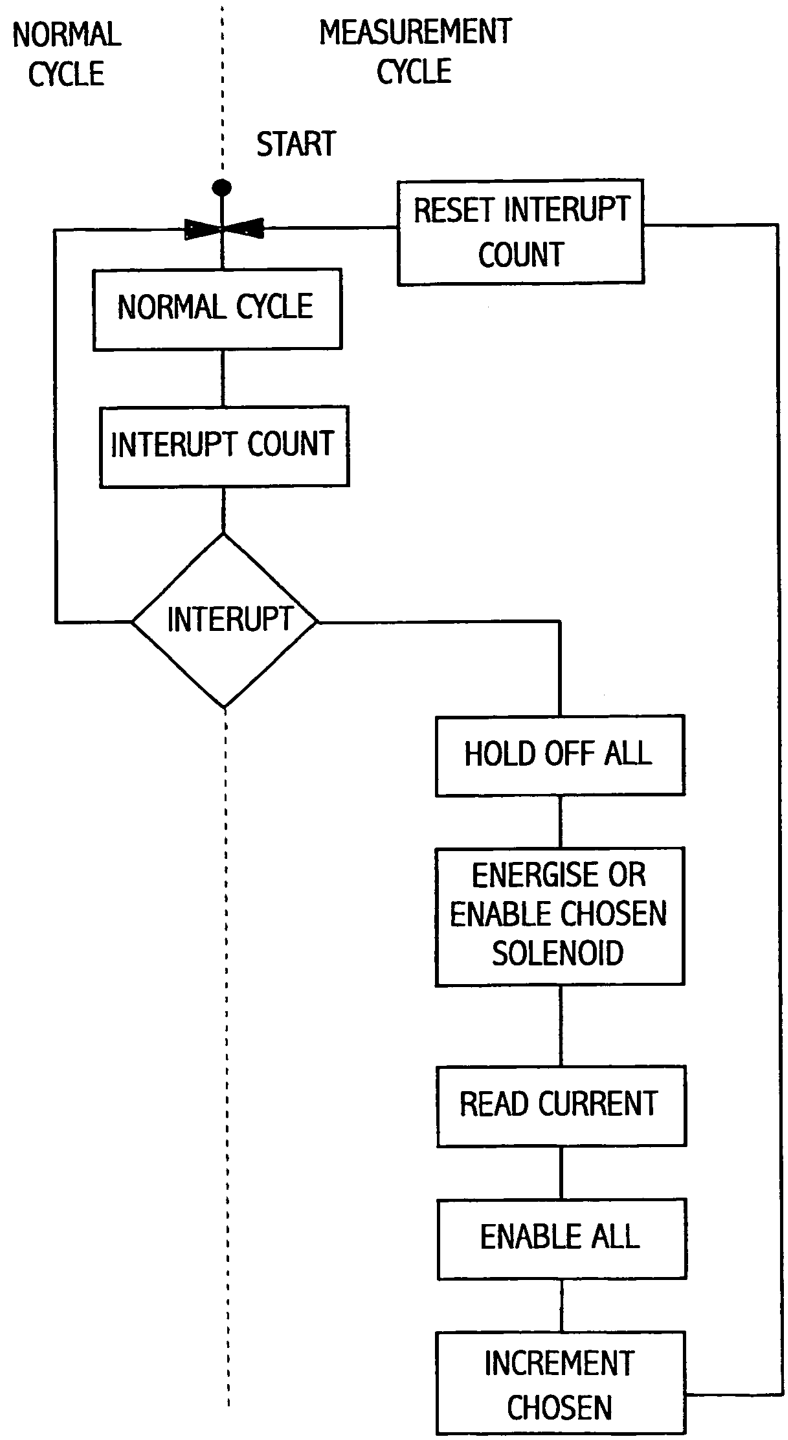
NORMAL CYCLE
MEASUREMENT CYCLE
START
RESET INTERUPT COUNT
NORMAL CYCLE
INTERUPT COUNT
INTERUPT
HOLD OFF ALL
ENERGISE OR ENABLE CHOSEN SOLENOID
READ CURRENT
ENABLE ALL
INCREMENT CHOSEN

FIG.7.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/04608

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01R19/165

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 932 246 A (DEUTSCH ROBERT W ET AL) 12 June 1990 (1990-06-12) claims 1,8	1-4
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 07, 29 September 2000 (2000-09-29) & JP 2000 112541 A (FUJITSU TEN LTD), 21 April 2000 (2000-04-21) abstract	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 January 2002	30/01/2002

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Ir nal Application No
I..../GB 01/04608

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US 4932246	A	12-06-1990	DE	4004427 A1	23-08-1990
			DE	4042519 C2	09-11-2000
JP 2000112541	A	21-04-2000	NONE		

Form PCT/ISA/210 (patent family annex) (July 1992)